2015

Odor and Odorous Chemical Emissions from Animal Buildings: Part 5. Simultaneous Chemical and Sensory Analysis with Gas Chromatography-Mass Spectrometry-Olfactometry

Shicheng Zhang
Fudan University

Jacek A. Koziel
Iowa State University, koziel@iastate.edu

Lingshuang Cai
DuPont Crop Protection

Steven J. Hoff
Iowa State University, hoffer@iastate.edu

Follow this and additional works at: http://lib.dr.iastate.edu/abe_eng_pubs

See next page for additional authors.
Odor and Odorous Chemical Emissions from Animal Buildings: Part 5. Simultaneous Chemical and Sensory Analysis with Gas Chromatography-Mass Spectrometry-Olfactometry

Abstract
Simultaneous chemical and sensory analyses using gas chromatography-mass spectrometry-olfactometry (GC-MS-O) for air samples collected at barn exhaust fans were used for quantification and ranking of the odor impacts of target odorous gases. Fifteen target odorous VOCs (odorants) were selected. Air samples were collected at dairy barns in Wisconsin and Indiana and at swine barns in Iowa and Indiana over a one-year period. The livestock facilities with these barns participated in the National Air Emissions Monitoring Study (NAEMS). Gas concentrations, odor character and intensity, hedonic tone, and odor peak area of the target odorants in air samples were measured simultaneously with GC-MS-O. The four individual odorants emitted from both dairy and swine sites with the largest odor impacts (measured as odor activity value, OAV) were 4-methyl phenol, butanoic acid, 3-methyl butanoic acid, and indole. The total odor (limited to target VOCs and referred to as the measured concentrations, odor intensities, and OAVs) emitted from the swine sites was generally greater than that from the dairy sites. The Weber-Fechner law was used to correlate measured odor intensities with chemical concentrations. Odorants with higher mean OAV followed the Weber-Fechner law much better than odorants with lower mean OAV. The correlations between odor intensities and chemical concentrations were much better for the swine sites (typically p < 0.05 and R^2 = 0.16 to 0.51) than for the dairy sites (typically p > 0.05 and R^2 < 0.15). Linking specific gases to odor could assist in the development and evaluation of odor mitigation technologies for solving livestock odor nuisance problems.

Keywords
Air quality, Animal feeding operations, Gas chromatography, Mass spectrometry, Odor, Olfactometry, Weber-Fechner law

Disciplines
Agriculture | Bioresource and Agricultural Engineering

Comments
This article is from Transactions of the ASABE 58(5): 1349-1359 (doi: 10.13031/trans.58.11123). Posted with permission.

Authors

This article is available at Iowa State University Digital Repository: http://lib.dr.iastate.edu/abe_eng_pubs/732
ODOR AND ODOROUS CHEMICAL EMISSIONS FROM ANIMAL BUILDINGS: PART 5.
SIMULTANEOUS CHEMICAL AND SENSORY ANALYSIS WITH GAS CHROMATOGRAPHY-MASS SPECTROMETRY-OLFACTOMETRY


ABSTRACT. Simultaneous chemical and sensory analyses using gas chromatography-mass spectrometry-olfactometry (GC-MS-O) for air samples collected at barn exhaust fans were used for quantification and ranking of the odor impacts of target odorous gases. Fifteen target odorous VOCs (odorants) were selected. Air samples were collected at dairy barns in Wisconsin and Indiana and at swine barns in Iowa and Indiana over a one-year period. The livestock facilities with these barns participated in the National Air Emissions Monitoring Study (NAEMS). Gas concentrations, odor character and intensity, hedonic tone, and odor peak area of the target odorants in air samples were measured simultaneously with GC-MS-O. The four individual odorants emitted from both dairy and swine sites with the largest odor impacts (measured as odor activity value, OAV) were 4-methyl phenol, butanoic acid, 3-methyl butanoic acid, and indole. The total odor (limited to target VOCs and referred to as the measured concentrations, odor intensities, and OAVs) emitted from the swine sites was generally greater than that from the dairy sites. The Weber-Fechner law was used to correlate measured odor intensities with chemical concentrations. Odorants with higher mean OAV followed the Weber-Fechner law much better than odorants with lower mean OAV. The correlations between odor intensities and chemical concentrations were much better for the swine sites (typically p < 0.05 and R² = 0.16 to 0.51) than for the dairy sites (typically p > 0.05 and R² < 0.15). Linking specific gases to odor could assist in the development and evaluation of odor mitigation technologies for solving livestock odor nuisance problems.

Keywords. Air quality, Animal feeding operations, Gas chromatography, Mass spectrometry, Odor, Olfactometry, Weber-Fechner law.

Larger and more concentrated livestock operations can lead to more frequent complaints of odor nuisance by surrounding communities. Some authors (Schiffman, 1998; Schiffman et al., 2005a, 2005b; Wing et al., 2008a, 2008b) have even suggested that odorants have potential environmental and health effects. Because of continuing concerns about livestock odor, there is an urgent need to determine levels of odor emission from livestock facilities. Presently, two general approaches are used to measure odor: indirectly by measuring individual gas concentrations in a gas mixture or directly by using human sensory methods such as olfactometry (Jacobson et al., 2008). The U.S. EPA has established several standards for measuring individual gas concentrations in air, such as TO-15 sampling in specially prepared whole air canisters and TO-17 sampling with sorbent tubes (EPA, 1999a, 1999b). More recently, Trabue et al. (2008) described a field sampling method for quantifying odorants in humid environments using sorbent tubes and thermal desorption gas chromatography-mass spectrometry.
(GC-MS). Dynamic forced-choice olfactometry is a standard method (Akdeniz et al., 2012a, 2012b) for quantifying total odor that relies on collecting air sample in inert bags for subsequent evaluation by panelists. Jacobson et al. (2008) described standard protocols for sampling and measuring odor emissions from livestock buildings using dynamic forced-choice olfactometry. Both approaches (direct and indirect) have strengths and weaknesses. Regulations based only on gas concentrations may reduce emissions of specific gases but not adequately address the odor sensed by people downwind from a source (Jacobson et al., 2008). Dynamic forced-choice olfactometry does not identify individual odorants that might be important to nuisance, health effects, and/or overall odor mitigation. Developing methods that link concentrations of individual gases with odor perception characteristics could be beneficial for scientists in determining potential health risks associated with livestock odor and for state and local regulatory agencies to enact science-based air standards that more adequately address odor issues.

Combining state-of-the art chemical and sensory analyses in the context of livestock odor was reported by Zhang et al. (2010). The method was developed to simultaneously analyze livestock air samples collected with sorbent tubes and GC-MS olfactometry (GC-MS-O). Method detection limits of GC-MS-O ranged from 0.02 to 3.46 μg m⁻³ (7 ppt to 1.46 ppt) for the 15 target odorants, i.e., significantly lower than the odor detection thresholds (ODTs), which are defined as the lowest mass concentration that is detectable by an average person. GC-MS-O offers the advantages of complementing sensory assessments with identification and quantification of individual odorants. This technique is used by the consumer product, flavor, and fragrance industries to identify odorants in complex natural mixtures from plants, fruits, foods, and product formulations (Zellner et al., 2008; Plutowska et al., 2008). Gallagher et al. (2008) proved that the combined use of GC-MS and GC-O is an effective methodology for analyzing the chemical composition of paint volatiles along with their sensory characteristics and holds promise for solving many indoor odor problems. Some researchers have reported using this method for identification of odorants from swine facilities (Koziel et al. 2006; Bulliner et al., 2006; Cai et al., 2006; Keener et al. 2002; Oehrl et al., 2001). Rabaud et al. (2002) used thermal desorption GC-MS-O to identify and quantify dairy farm odorants. To date, limited research exists on simultaneous chemical and sensory analyses of livestock odorants (Zahn et al., 2001a, 2001b; Zhang et al., 2010). Additionally, quantifying odor emissions from animal agriculture is a complex process, and few researchers and engineers have taken on the difficult task (Jacobson et al., 2008).

This study was funded by the USDA National Research Initiative and supplemented the National Air Emission Monitoring Study (NAEMS) with comprehensive measurements of odor emissions and chemical analyses of odorants from four NAEMS animal production sites, including two swine and two dairy sites. Prior studies on prioritization of livestock odorants (Wright et al., 2005; Koziel et al., 2006; Bulliner et al., 2006) served as guides to limit the scope of this work to volatile fatty acids (VFAs) and phenolics, i.e., a total of 15 odorants. Later, additional sulfur-containing VOCs (SVOCs) were added to the quantification method (Cai et al., 2015). However, SVOCs were not analyzed due to the limited available data.

In this work, we build on the previous work (Koziel et al., 2006; Bulliner et al., 2006; Lo et al., 2008; Zhang et al., 2010) and apply the same method and concept of simultaneous chemical and sensory analyses to gas samples collected from four livestock facilities (two dairy barns in Wisconsin and Indiana and two swine barns in Iowa and Indiana) over a one-year period. The objectives of this study were to (1) further evaluate the validity of the GC-MS-O method for simultaneous chemical and sensory analyses of livestock odorants, (2) delineate the most significant gases that contribute to relative odor impacts of livestock buildings, and (3) determine the correlations between measured odor intensities and chemical concentrations of 15 target odorants.

**Materials and Methods**

**Sample Collection and Analyses**

The detailed experimental procedures were described by Zhang et al. (2010) and in Parts 1, 2, 3, 4, and 6 of this series (Bereznicki et al., 2012; Akdeniz et al., 2012a, 2012b; Cai et al., 2015; Parker et al., 2012). Briefly, VOC samples were collected from November 2007 to April 2009 at the following four livestock facilities: dairy site WI5B in Wisconsin (number of air sampling events n = 26), dairy site IN5B in Indiana (n = 26), sow farm IA4B in Iowa (n = 39), and swine finishing facility IN3B in Indiana (n = 26). Fifteen odorant compounds were targeted for quantification based on previous studies of odorants emitted from livestock facilities (Lo et al., 2008; Koziel et al., 2006; Bulliner et al., 2006; Cai et al., 2006; Keener et al., 2002; Oehrl et al., 2001). Sulfur VOCs were not quantified due to system limitations. Standard solutions for gas standards were prepared by diluting standard stock solutions in methanol and were stored in the dark at 4°C.

Simultaneously chemical and sensory analyses were performed by using thermal desorption for air samples collected using Tenax-TA sorbent tubes and the GC-MS-O system. Simultaneous chemical and sensory analyses were facilitated by VOC separation on the GC column, followed by an eluent split between two detectors: the mass selective detector (MSD) and the olfactory detection (sniff) port. Trained human panelists (one per sample) were used to sniff separated compounds simultaneously with chemical analyses (figs. 1 and 2). There was no replication of sensory analyses. Concentrations of 15 odorants were quantified. Simultaneously, odor character, odor intensity (I, category scaling on a scale of 0% to 100%), odor duration (D, min; chromatography column retention time difference between the first detection of specific odor to no further detection by a panelist), odor peak area (I × D × 100, a surrogate measure of odor persistence at the sniff port), and hedonic tone (on a scale of -4 to 4) of individual compounds were measured and recorded during sample analysis with the GC-MS-O system (Zhang et al., 2008, 2010). The measurement of
odor intensity at the GC-MS-O sniff point is different from the dilution-to-threshold method. The panelist uses a 0% to 100% scale to assess and record the odor intensities of separated odorants as they elute from the GC column into the sniff port. The panelists are trained to apply the following seven levels of perceived odor intensity: (1) very faint odor or not sure if detected = 5%, (2) very faint odor detected = 10%, (3) faint odor = 30%, (4) mild odor = 50%, (5) strong odor = 70%, (6) very strong odor = 90%, and (7) extreme non-tolerable odor, remove nose from the sniff port = 100%. The odor peak area is the product of $I \times D \times 100$.

For some compounds with longer odor durations, such as $p$-cresol, 4-ethylphenol, 2-aminoacetophenone, indole, and skatole (Zhang et al., 2008), odor intensity may be relatively low yet the odor effect is large due to the longer duration. The odor peak area was used to characterize the total effect of individual odorants.

**CORRELATION BETWEEN ODOR INTENSITIES AND CHEMICAL CONCENTRATIONS**

Correlation and regression analyses were conducted to evaluate potential correlations between individual chemical concentrations and measured odor intensities recorded by trained panelists using GC-MS-O. Several models are used for fitting the relationship between odorant intensity and chemical concentration. According to the literature (Audouin et al., 2001; Zhang et al., 2010), the Weber-Fechner law is the best model for fitting the chemical concentrations and odor intensities measured with the category scaling method. In this study, the Weber-Fechner law was used (Audouin et al., 2001; Zhang et al., 2010):

$$I = m \times \log C + b \quad (1)$$

where $I$ is the measured odor intensity (category scaling, 0% to 100% by panelist at the sniff port), $C$ is the measured chemical (VOC) concentration ($\mu g m^{-3}$), $m$ is a stimulus-dependent constant that represents the slope of the linear function, and $b$ is a stimulus-dependent constant that represents the y-axis intercept. Several assumptions were made in using the Weber-Fechner law (eq. 1). Mathematically, the VOC concentration should not be zero. Thus, the not-quantifiable concentrations were not used. Secondly, the odor intensity was assumed to be equal to zero and independent of the chemical concentration for cases where measured VOC concentrations were below their ODTs. Therefore, data pairs with VOC concentrations less than the odor detection limit and odor intensities equal to zero were not used, i.e., when both conditions were met (not just one of them), the pair of data was not used. All statistical analyses were conducted using SPSS Statistics version 17.0 (SPSS, 2007).

**ODOR ACTIVITY VALUES (OAV)**

The odor intensity for individual compounds is dependent not only on the chemical concentration but also on the
ODT, i.e., the lowest concentration in mass/volume units that is perceivable with the human sense of smell (Bi and Ennis, 1998). Each individual chemical has a different ODT, which is typically known for a small subset of odorants. The odor activity value (OAV) is the ratio of the measured gas concentration to the ODT. The OAV concept was used to analyze the effects of chemical concentration and ODT on odor intensity. To date, OAV has been used in research related to livestock air quality (Trabue et al., 2008; Parker et al., 2012). Table 1 lists ODTs cited from Devos et al. (a) and (b)
al. (1990). The mean OAV was estimated as the mean measured concentration of the individual VOC divided by its ODT. The method of odor intensity (I) measurement using GC-MS-O was different from that in the literature citing olfactometry with whole air samples. The GC-MS-O method might be more sensitive in some cases. This is because panelists can detect odorants that were measured at concentrations below the odor detection limits due to the pre-concentration (enhancement) on the sorbent tubes during air sampling. Therefore, it is reasonable that the concentrations of some compounds in the eluents were below the ODT while their OAVs were less than 1 (tables 1 to 3 and fig. 3). Measured odor intensities were still reported. ODT values in the literature (Devos et al., 1990; AIHA, 1989; Nagata, 2002) are also associated with uncertainties.

### RESULTS AND DISCUSSION

#### CHEMICAL CONCENTRATIONS AND ODOR INTENSITIES

The odor samples were analyzed for chemical concentrations, odor character, odor intensity, odor peak area, and hedonic tone simultaneously using GC-MS-O similarly to methods described by Koziel et al. (2006), Bulliner et al. (2006), Lo et al. (2008), and Zhang et al. (2008, 2010).

Table 1 summarizes the measured VOC concentrations, odor character, odor intensity, odor peak area, and hedonic tone associated with the 15 target odorants in air samples collected at a swine site and a dairy site. Greater VOC concentrations and odor intensities were associated with swine operations compared with dairies (Table 1). In addition, VFA concentrations were higher than phenolics at both swine and dairy operations. Measured hedonic tones ranged from -2 to -3 for all target compounds, confirming their unpleasant odor. A summary of the measured VOC concentrations and calculated emission rates is presented by Cai et al. (2015). Figure 3 summarizes the mean measured VOC concentrations, odor intensities, odor peak areas (product of measured odor duration and odor intensity I), hedonic tones, and OAVs of air samples from all four sites. Chemical concentrations did not have an apparent proportionality correlation with odor intensity, odor peak area, or hedonic tone. For example, the top three dairy VOCs with the highest concentrations were acetic acid, propanoic acid, and butanoic acid (fig. 3a). However, the mean odor intensities of these three VOCs were not in the top three (fig. 3b), most likely because they were coupled with relatively high ODTs (table 1), which offset the impacts described by their OAVs. Measured odor intensity and OAV may be more suitable than chemical concentration for representing human responses to swine or dairy sites. The VOCs that were consistently associated with greater odor intensity (fig. 3b) at dairy sites were acetic acid, butanoic acid, 3-methyl butanoic acid, and 2-methoxy phenol. The VOCs that were consistently associated with greater odor intensity (fig. 3b) at swine sites were butanoic acid, 3-methyl butanoic acid, pentanoic acid, 2-methoxy phenol, and 4-methyl phenol. These VOCs are responsible for the characteristic odor of livestock operations.

Our previous work showed that the recorded odor duration D (i.e., the time span in the aromagram during which odor was detected at the sniff port) increased with the increase in GC column retention time (Zhang et al., 2010). Thus, the compounds with greater GC column retention time and therefore also greater molecular weight and lower vapor pressure, such as 2-methoxy phenol, heptaenoic acid, phenol, 4-methyl phenol, 4-ethyl phenol, 1-(2-amino phenyl) phenone, indole, and 3-methyl-1H-indole, tended to be more persistent odorants and “linger” at the sniff port longer (Zhang et al., 2010). This was likely due to vapor condensation occurring immediately after elution from the heat-traced sniff port into the cooler glass cone, the air, and the nose of the panelist. This phenomenon is
not unlike the same odorants being very persistent in certain environments with a history of chronic exposure to these potent odorants. The exact reason behind this phenomenon is not well understood. However, it is thought to be a combination of the physicochemical properties of VOCs (semi-VOCs) and the physiology of the human sense of smell. Figure 3c summarizes the odor peak area (defined as $I \times D \times 100$) (table 1). It is interesting to note that VOCs such as butanoic acid, 3-methyl butanoic acid, 2-methoxy phenol, 4-methyl phenol, 4-ethyl phenol, 1-(2-aminophenyl) phenone, indole, and 3-methyl-1H-indole tended to stand out and were associated with greater odor peak areas.
The hedonic tone represents the level of odor pleasantness or unpleasantness. The hedonic tone did not change significantly with odorant concentrations. All 15 VOCs were unpleasant odorants with negative values of hedonic tone. Eleven odorants had hedonic tone values consistently lower than -2, i.e., butanoic acid, 3-methyl butanoic acid, pentanoic acid, hexanoic acid, 2-methoxy phenol, heptanoic acid, 4-methyl phenol, 4-ethyl phenol, 1-(2-aminophenyl) phenone, indole, and 3-methyl-1H-indole (fig. 3d). Not surprisingly, these compounds are associated with the gases emitted from manure (Lo et al., 2008).

Eight VOCs had mean OAVs greater than 1.0 at swine operations, i.e., propanoic acid, butanoic acid, 3-methyl butanoic acid, pentanoic acid, 2-methoxy phenol, heptanoic acid, 4-methyl phenol, and indole. The four VOCs with OAVs greater than 1.0 were butanoic acid, 3-methyl butanoic acid, pentanoic acid, and hexanoic acid, respectively. The five VOCs with OAVs greater than 0.2 were acetic acid, propanoic acid, 3-methyl butanoic acid, 2-methoxy phenol, and phenol.

CORRELATIONS BETWEEN ODOR INTENSITIES AND CHEMICAL CONCENTRATIONS

In our previous work (Zhang et al., 2010), we showed that the correlations between measured odor intensities and mass (concentration) of standard odorants followed the fundamental Weber-Fechner law. In this study, the same model was used instead of standard gases to analyze the air samples. Tables 2 and 3 provide the correlations between measured odor intensities (I) and VOC concentrations (C). The results indicate that the significance of the correlations was different between dairy and swine sites. Figure 4 shows the correlations of acetic acid and 4-methyl phenol emitted from four sites. The slopes of the correlations associated with swine sites were significant for eight VOCs at site IA4B and for 11 VOCs at site IN3B. The seven common VOCs for both sites with p < 0.05 were acetic acid, butanoic acid, 3-methyl butanoic acid, 2-methoxy phenol, phenol, 4-methyl phenol, and 4-ethyl phenol. The slopes of the correlations associated with swine sites were significant for all VOCs except for ethyl acetate and 2-methyl butanoic acid.

### Table 2. Correlations between measured odor intensities (I) and chemical concentrations (C) of typical odorants emitted from dairy sites.

<table>
<thead>
<tr>
<th>Odorant[^1]</th>
<th>OAV</th>
<th>mI</th>
<th>mC</th>
<th>R²</th>
<th>p</th>
</tr>
</thead>
<tbody>
<tr>
<td>AA</td>
<td>4.03</td>
<td>28</td>
<td>0.093</td>
<td>0.004</td>
<td>0.697</td>
</tr>
<tr>
<td>PPA</td>
<td>4.02</td>
<td>27</td>
<td>0.34</td>
<td>0.15</td>
<td>0.815</td>
</tr>
<tr>
<td>MPA</td>
<td>4.02</td>
<td>26</td>
<td>0.76</td>
<td>0.003</td>
<td>0.803</td>
</tr>
<tr>
<td>BA</td>
<td>4.01</td>
<td>25</td>
<td>0.93</td>
<td>0.002</td>
<td>0.815</td>
</tr>
<tr>
<td>MBA</td>
<td>4.01</td>
<td>24</td>
<td>0.99</td>
<td>0.001</td>
<td>0.803</td>
</tr>
<tr>
<td>PTA</td>
<td>4.00</td>
<td>23</td>
<td>1.00</td>
<td>0.000</td>
<td>0.803</td>
</tr>
<tr>
<td>HXA</td>
<td>4.00</td>
<td>22</td>
<td>1.00</td>
<td>0.000</td>
<td>0.803</td>
</tr>
<tr>
<td>2MPL</td>
<td>4.00</td>
<td>21</td>
<td>1.00</td>
<td>0.000</td>
<td>0.803</td>
</tr>
<tr>
<td>HPA</td>
<td>4.00</td>
<td>20</td>
<td>1.00</td>
<td>0.000</td>
<td>0.803</td>
</tr>
<tr>
<td>PL</td>
<td>4.00</td>
<td>19</td>
<td>1.00</td>
<td>0.000</td>
<td>0.803</td>
</tr>
<tr>
<td>4MPL</td>
<td>4.00</td>
<td>18</td>
<td>1.00</td>
<td>0.000</td>
<td>0.803</td>
</tr>
<tr>
<td>4EPL</td>
<td>4.00</td>
<td>17</td>
<td>1.00</td>
<td>0.000</td>
<td>0.803</td>
</tr>
<tr>
<td>2APP</td>
<td>4.00</td>
<td>16</td>
<td>1.00</td>
<td>0.000</td>
<td>0.803</td>
</tr>
<tr>
<td>IND</td>
<td>4.00</td>
<td>15</td>
<td>1.00</td>
<td>0.000</td>
<td>0.803</td>
</tr>
<tr>
<td>3MHI</td>
<td>4.00</td>
<td>14</td>
<td>1.00</td>
<td>0.000</td>
<td>0.803</td>
</tr>
</tbody>
</table>

[^1]: n = subset sample number used for mean, mC = mean measured concentrations, mOAV = mean measured concentrations divided by ODT, mI = mean measured odor intensity, C = stimulus-dependent constant that represents the slope of the linear function, b = stimulus-dependent constant that represents the y-axis intercept in equation 1, R² = coefficient of determination, and p = p-value at the 5% significance level. R² values in bold type are significant. All data were natural log-transformed. AA = acetic acid, PPA = propanoic acid, MPA = 2-methyl propanoic acid, BA = butanoic acid, MBA = 3-methyl butanoic acid, PTA = pentanoic acid, HXA = hexanoic acid, 2MPL = 2-methoxy phenol, HPA = heptanoic acid, PL = phenol, 4MPL = 4-methyl phenol, 4EPL = 4-ethyl phenol, 2APP = 1-(2-aminophenyl) phenone, IND = indole, and 3MHI = 3-methyl-1H-indole.
dairy sites were statistically insignificant (p > 0.05) except for pentanoic acid. Tables 2 and 3 also summarize the coefficients of determination (R²) and p-values. One possible reason for the differences in the statistical significance of the I and C correlations (eq. 1) for swine and dairy operations was apparently associated with OAV. Measured VOC concentrations at dairy operations were generally lower, resulting in low OAV. Resulting OAVs were also associated with the greater variability inherent with weak odorants and their detection by the human nose. The mean OAVs for the compounds from swine sites were much larger than those from dairy sites (fig. 3e). In addition, perceived odor intensities (I) for VOCs associated with dairy sites were generally lower (tables 1 and 2).

Nine swine barn VOCs (table 3) that exhibited relatively good correlations (p < 0.05) between measured odor intensity and chemical concentration and had high OAVs were acetate, butanoic acid, 3-methyl butanoic acid, 2-methoxy phenol, phenol, 4-methyl phenol, 4-ethyl phenol, and 3-methyl-1H-indole. The R² values for these compounds ranged from 0.14 to 0.69 and were generally lower than those reported by Zhang et al. (2010), who used standard gases and slightly higher concentrations. These odorous VOCs are priority odorants consistently associated with livestock operations. The correlations of dairy VOCs were typically insignificant (p > 0.05) with R² < 0.27.

**CONCLUSIONS**

The following conclusions were drawn from this research:

- Simultaneous chemical and sensory analyses with GC-MS-O of 15 typical VOCs associated with livestock odor, including chemical concentration, odor character, odor intensity, odor peak area, and hedonic tone, is potentially useful for fundamental work on linking overall odor with specific compounds in real-world cases.

- The odorants associated with swine sites had much higher OAVs than the dairy sites odorants. The VOCs with the highest OAVs were butanoic acid, 4-methyl phenol, indole, 3-methyl butanoic acid, and pentanoic acid (table 3). Dairy OAVs were significantly lower (fig. 3e and table 2). Only one odorant (butanoic acid) had a mean OAV greater than 1. The top four odorants with OAVs between 0.2 and 1 were acetate, propanoic acid, 3-methyl butanoic acid, and 4-methyl phenol.

- Odorants with higher OAVs followed the Weber-Fechner law. Correlations between odor intensity and chemical concentration were much better for swine sites than for dairy sites. Specifically, swine operations were associated with the most p-values less than
0.05 and the most $R^2$ values between 0.14 and 0.68, as compared with dairy operations where most p-values were greater than 0.05 and most $R^2$ values were less than 0.27.

**ACKNOWLEDGEMENTS**

This research was funded by USDA-NRI Grant No. 2005-35112-15336 entitled “Odor Emissions and Chemical Analysis of Odorous Compounds from Animal Buildings.”


